

# Auditory Fitness for Duty: A Review

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## Abstract

**Background:** *Auditory fitness for duty* (AFFD) refers to the possession of hearing abilities sufficient for safe and effective job performance. In jobs such as law enforcement and piloting, where the ability to hear is critical to job performance and safety, hearing loss can decrease performance, even to the point of being hazardous to self and others. Tests of AFFD should provide an employer with a valid assessment of an employee's ability to perform the job safely, without discriminating against the employee purely on the basis of hearing loss.

**Purpose:** The purpose of this review is to provide a basic description of the functional hearing abilities required in hearing-critical occupations, and a summary of current practices in AFFD evaluation. In addition, we suggest directions for research and standardization to ensure best practices in the evaluation of AFFD in the future.

**Research Design:** We conducted a systematic review of the English-language peer-reviewed literature in AFFD. "Popular" search engines were consulted for governmental regulations and trade journal articles. We also contacted professionals with expertise in AFFD regarding research projects, unpublished material, and current standards.

**Results:** The literature review provided information regarding the functional hearing abilities required to perform hearing-critical tasks, the development of and characteristics of AFFD protocols, and the current implementation of AFFD protocols.

**Conclusions:** This review paper provides evidence of the need to institute job-specific AFFD protocols, move beyond the pure-tone audiogram, and establish the validity of test protocols. These needs are arguably greater now than in times past.

**Key Words:** Auditory fitness for duty, auditory perception, functional hearing ability, occupational health and safety, speech perception

**Abbreviations:** ADA = Americans with Disabilities Act; AFFD = auditory fitness for duty; C&P = Conservation and Protection; CCG = Canadian Coast Guard; DFO = Department of Fisheries and Oceans Canada; HINT = Hearing in Noise Test; HPDs = hearing protection devices; PTA = pure-tone average; SNR = signal-to-noise ratio; SPIN = Speech Perception in Noise Test; SPRINT = Speech Recognition in Noise Test; WIN = Words in Noise Test

An inability to hear can be a liability in the workplace. In some occupations, hearing loss is a contributing factor to stress, accidents, injuries, and fatalities (Zwerling et al, 1997; Hager, 2002; Morata et al, 2005; Kramer et al, 2006). For example, Kramer et al (2006) surveyed a sample of 210 normal-hearing and hearing-impaired individuals with different educational levels and various jobs using the

*Amsterdam Checklist for Hearing and Work* (Kramer et al, 2006). They found that hearing-impaired workers took more sick leave overall than the normal-hearing group. When the reasons for sick leave were analyzed, the hearing-impaired workers were just as likely as normal-hearing workers to have taken sick leave for "regular" reasons such as a cold or fever over a 12-month time period. However, when amount of sick

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leave due to mental distress was analyzed over the same time period, the hearing-impaired group was found to have taken five times more sick leave for this reason than their normal-hearing counterparts. In another example, hearing loss greater than 20 dB HL at 4000 Hz was found to be one of the three main risk factors for injury at a Danish shipyard over a two-year monitoring period (Moll van Charante and Mulder, 1990). A number of fatalities have been caused by vehicles backing up at construction sites. In at least some of these cases, the victims did not appear to notice the warning beeper signal (Laroche et al, 1993). Competing noise and noise-induced hearing loss have been postulated as contributing factors in such accidents (Lipscomb et al, 2000; Deshaies et al, 2008).

The extent to which hearing loss contributes to injuries and fatalities in the workplace is difficult to ascertain. Incident report forms often do not record environmental conditions, and noise or hearing loss may not be identified specifically as a contributing factor (Brogan, 2001; Hager, 2002; Deshaies et al, 2008). Nevertheless, anecdotal case reports abound of injuries or fatalities caused by an inability to hear alarms, warning signals, or the cries of coworkers who have gotten clothing or hands caught in machines (Hétu et al, 1995; Lipscomb et al, 2000; Brogan, 2001; Hager, 2002; Suter, 2007).

Hearing loss can be a dangerous liability in military missions (Price et al, 1989; Garinther and Peters, 1990; Forshaw and Hamilton, 1997; Office of the Surgeon General, U.S. Army, 2006). Using model simulations of sound propagation and hearing ability, Price and colleagues (1989) demonstrated that a person with normal hearing could detect footsteps in leaves at a distance of 100 m, whereas a person suffering from a sloping mild to moderately-severe hearing loss would first hear footfalls at a distance of 0.6 m; individuals with this hearing loss and a 10–15 dB superimposed temporary threshold shift would not be able to hear the footsteps at all. This difference in distance would reduce the hypothetical warning time available for responding to the approach of enemy personnel from two minutes to nearly zero (Price et al, 1989).

Garinther and Peters (1990) showed that mission performance varies as a function of ease of communication. They simulated gunnery scenarios with 30 experienced tank crews in communication conditions ranging from very good to very poor. As communication became more difficult, the mean time to identify a target, the percentage of commands incorrectly communicated, the percentage of time the crew was “killed” by the enemy, and the percentage of times the wrong target was “shot” all increased, while the percentage of targets correctly identified and the percentage of enemy targets “killed” decreased. These differences occurred in spite of the well-defined nature

of the gunnery task and the limited vocabulary employed in the scenarios.

As the examples above illustrate, the ability to hear is essential in many occupations. Even occupations that do not involve physical safety, such as that of a professional musician, may require the ability to hear. Auditory fitness for duty (AFFD) refers to the possession of hearing abilities sufficient for safe and effective job performance. Typically, AFFD is evaluated in occupations that are physically hazardous or that involve the safety of others (e.g., operation of motor vehicles or aircraft, mining, firefighting, law enforcement, military, etc.). The assessment of AFFD usually involves, at the very least, obtaining an audiogram at selected frequencies. In the United States, the Department of Defense establishes AFFD standards for entrance into the U.S. military (Department of Defense, 2005). For federal civilian jobs, the Office of Personnel Management establishes AFFD standards (LaCroix, 1996a). State agencies, and even private companies, may adopt federal AFFD protocols or establish their own standards.

AFFD tests may be given prior to employment or on an ongoing basis. Results are compared against pre-established norms or criteria. The individual may be found (1) capable of safely performing his/her job; (2) capable of safely performing his/her job with accommodation(s); or (3) incapable of safely performing his/her job, necessitating restriction from that job (Begines, 1995). The final disposition of an individual is determined on the basis of AFFD test results, job requirements, amount of on-the-job experience, legal considerations, and the needs of the organization (Begines, 1995; LaCroix, 1996b). As we discuss in greater detail later, it is generally assumed that an individual who meets the AFFD standards for a particular job possesses sufficient hearing to perform that job safely and effectively, even though that assumption may never have been validated.

While decisions regarding AFFD are ultimately made by management (Begines, 1995; LaCroix, 1996b), the evaluation of AFFD and the development of AFFD standards fall naturally within an appropriately trained audiologist's scope of practice (Punch et al, 1996; American Academy of Audiology, 2004; American Speech-Language-Hearing Association, 2004). Punch and colleagues (1996), in their report to the Michigan Law Enforcement Officers Training Council, recommended that all AFFD testing of state police officer candidates be performed by a qualified audiologist. According to the American Academy of Audiology (2004), “the profession of audiology is concerned with all auditory impairments and their relationship to disorders of communication.” Nevertheless, much of the available information on AFFD standards and practices falls outside the range of sources regularly

consulted by audiologists. Therefore, a consolidation of a significant portion of the existing literature on AFFD, available in a journal devoted to audiology, may be useful to audiologists interested in or working in this area.

The purposes of this article are (1) to review the AFFD literature and current AFFD practices, (2) to describe the functional hearing abilities required in most hearing-critical occupations and the effects of hearing loss on functional abilities, (3) to review tests of AFFD as well as the basis and development of AFFD protocols, and (4) to suggest directions for research and standardization to ensure best practices in the evaluation of AFFD in the future. Implicit in the development of this review is the assumption that the audiologist, in close consultation with job content experts, is the professional most qualified to develop, implement, and interpret AFFD standards.

## METHOD AND SCOPE OF REVIEW

For this review, multiple online searches of the peer-reviewed literature were conducted in PsycInfo, PubMed, and Scopus using Boolean descriptors with relevant search terms (e.g., “work or occupation or job or duty AND fitness or readiness AND hearing”). The reference sections of papers found during the initial searches were scanned for additional relevant articles. “Popular” search engines such as Google, Google Scholar, and Google Uncle Sam were used to find sources such as governmental regulations and trade journal articles. All searches were limited to sources in English; no limits were placed on year of publication. Occasionally, professionals with expertise in AFFD were consulted regarding research projects, unpublished material, and current standards. Sources were included in this review if they provided descriptive or experimental evidence or information about one or more of the following general areas: (1) functional hearing abilities required to perform hearing-critical tasks; (2) development of and characteristics of AFFD protocols; and (3) current implementation of AFFD protocols.

## OVERVIEW OF AFFD TESTING

Numerous occupations require good hearing. Among the jobs specifically identified in the AFFD literature as having hearing-critical components are acoustic engineering (Fleishman and Reilly, 1992); airline piloting and traffic control (Coles and Sinclair, 1988; MacLean, 1995; LaCroix, 1996a); driving public service, passenger-carrying, or commercial transport vehicles and taxis (Lee et al, 1981; Coles and Sinclair, 1988; MacLean, 1995; LaCroix, 1996a; Casali et al, 1998; R. Dietz, pers. comm., Jan. 15, 2008); firefighting (LaCroix, 1996a; MacLean, 2001); law enforcement

(MacLean, 1995; Punch et al, 1996; Goldberg, 2001; Cook and Hickey, 2003); manufacturing (Hétu et al, 1995); military and Coast Guard service (Coles and Sinclair, 1988; Marshall and Carpenter, 1988; Fleishman and Reilly, 1992; Hodgson et al, 1999; MacLean, 1995; Forshaw and Hamilton, 1997; Campbell and Catano, 2004; Office of the Surgeon General, U.S. Army, 2006); mining (LaCroix, 1996a); nursing (Fleishman and Reilly, 1992; MacLean and Nilsson, 1997); radio operation (Coles and Sinclair, 1988); and railroad engineering (MacLean, 1995). While not exhaustive, this list demonstrates the diversity of occupations in which good hearing is vitally important.

Table 1 lists some of the AFFD test protocols currently in use in various occupations in the military and public service. Individuals must meet these standards prior to induction or employment. AFFD testing may also be conducted periodically throughout employment. For instance, the U.S. Army requires annual audiometric monitoring of those soldiers “who are routinely exposed to noise, assigned to a deployable unit, or are within 12 months of deploying” (McIlwain, 2009, p. 6). Most AFFD guidelines require hearing evaluations to be conducted by a supervised audiometric technician, an occupational hearing conservationist certified by the Council for Accreditation of Occupational Hearing Conservationists, or a licensed and/or certified audiologist.

## Pure-Tone Threshold Testing

The most common test of AFFD is the pure-tone audiogram. An audiogram is easy to administer and interpret, and norms for pure-tone detection thresholds are readily available. If thresholds fall within normal limits, then the employee is generally assumed to have sufficiently good functional hearing to perform his or her job safely and effectively.

As can be seen in Table 1, the choice of pure-tone test frequencies and passing cutoff values varies somewhat, though not greatly, from occupation to occupation. At the very least, all pure-tone test protocols require testing at 500, 1000, and 2000 Hz. Cutoff values at each of these three frequencies generally fall between 20 and 35 dB HL, although jobs with extreme auditory demands, such as military piloting, may have more stringent criteria (see Table 1, U.S. Army Aviation and Air Traffic Control Class 1/1A). Testing at higher frequencies (3000, 4000, and 6000 Hz) is often required, although the choice of specific test frequencies and cutoff values is more variable at these frequencies. In addition, protocols vary as to whether one ear or both ears must pass pure-tone threshold criteria and/or whether a certain degree of asymmetry between ears is acceptable. For example, the appointment, enlistment, and induction

**Table 1. Current AFFD Criteria for Selected Occupations**

Test Frequencies (Hz)	U.S. Army		U.S. Army		U.S. Army		U.S. Navy and		U.S. Navy and		U.S. Navy		
	US Air Force Academy <sup>5</sup>	US Air Force Academy <sup>5</sup>	Aviation and Air Traffic Control Classes 1/1A <sup>3</sup>	Aviation and Air Traffic Control Classes 2/2F/3/4 <sup>3</sup>	Police and Guard Series <sup>6</sup>	U.S. Marine Corps Class I Aviators <sup>4</sup>	U.S. Navy and Aviation Personnel—Student Naval Aviator and Most Class II Applicants <sup>4</sup>	Marine Corps	U.S. Navy and Marine Corps Special Submarine Duty <sup>4</sup>	U.S. Navy and Marine Corps	U.S. Navy and Marine Corps	U.S. Navy Landing Craft Air Cushion <sup>4</sup>	
500	≤35 dB	<35 dB	≤25 dB	≤25 dB	≤35 dB	≤35 dB	≤25 dB	≤35 dB	≤35 dB	≤35 dB	≤35 dB	≤35 dB	
1000	≤35 dB	<35 dB	≤25 dB	≤25 dB	≤35 dB	≤30 dB	≤25 dB	≤35 dB	≤35 dB	≤35 dB	≤35 dB	≤30 dB BE/≤50 dB PE	
2000	≤35 dB	<35 dB	≤25 dB	≤25 dB	≤35 dB	≤30 dB	≤25 dB	≤35 dB	≤35 dB	≤35 dB	≤35 dB	≤30 dB BE/≤50 dB PE	
3000	≤45 dB	≤45 dB	≤35 dB	≤35 dB	≤55 dB	≤30 dB BE/≤50 dB PE	≤45 dB	≤45 dB	≤45 dB	≤45 dB	≤45 dB	≤45 dB	
4000	≤55 dB	≤55 dB	≤45 dB	≤55 dB	≤30 dB	≤30 dB	≤55 dB	≤55 dB	≤55 dB	≤55 dB	≤55 dB	≤55 dB	
6000	≤30 dB	≤30 dB	≤45 dB	≤65 dB									
PTA (500, 1000, 2000)													
Other Required Criteria													
HA Use Allowed?	N	N	N	N	Only allowed in further testing							Must show ability to communicate verbally and perform duties	
Further Testing if Don't Pass?	N	N			Full audiological evaluation and WR in noise								
<b>U.S. Dept. of the Interior Law Enforcement—U.S. National Park Service (Commissioned Park Rangers, Criminal Investigators, Correctional Officers) and U.S. Fish and Wildlife Service (Special Agents)<sup>7</sup></b>													
500	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	"Normal findings" in BE
1000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	"Normal findings" in BE
2000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	"Normal findings" in BE
3000	≤40 dB	≤45 dB	≤45 dB	≤45 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	"Normal findings" in BE
4000		≤45 dB	≤45 dB	≤45 dB									
6000		≤25 dB including 3000 Hz											
PTA (500, 1000, 2000)		PE PTA not more than 15 dB worse than BE PTA; 4000 and 6000 Hz in PE not more than 30 dB worse than in BE											≤25 dB at 1000, 2000, and 3000 Hz
Other Required Criteria					Must be able to hear whispered voice at 15 feet with each ear without hearing aid								
HA Use Allowed?	N	N	N	N									Y
Further Testing if Don't Pass?	Full audiological evaluation and HINT												Only allowed in further testing SPT, WR in quiet and noise
<b>U.S. Dept. of Treasury—U.S. Customs Service—Canine Enforcement Officer and Border Protection Officer Series<sup>8</sup></b>													
500	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
1000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
2000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
3000	≤40 dB	≤45 dB	≤45 dB	≤45 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB
4000		≤45 dB	≤45 dB	≤45 dB									
6000		≤25 dB including 3000 Hz											
PTA (500, 1000, 2000)		PE PTA not more than 15 dB worse than BE PTA; 4000 and 6000 Hz in PE not more than 30 dB worse than in BE											≤25 dB at 1000, 2000, and 3000 Hz
Other Required Criteria					Must be able to hear whispered voice at 15 feet with each ear without hearing aid								
HA Use Allowed?	N	N	N	N									Y
Further Testing if Don't Pass?	Full audiological evaluation and HINT												Only allowed in further testing SPT, WR in quiet and noise
<b>U.S. Dept. of Homeland Security—Border Patrol Agents<sup>9</sup></b>													
500	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
1000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
2000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
3000	≤40 dB	≤45 dB	≤45 dB	≤45 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB
4000		≤45 dB	≤45 dB	≤45 dB									
6000		≤25 dB including 3000 Hz											
PTA (500, 1000, 2000)		PE PTA not more than 15 dB worse than BE PTA; 4000 and 6000 Hz in PE not more than 30 dB worse than in BE											≤25 dB at 1000, 2000, and 3000 Hz
Other Required Criteria					Must be able to hear whispered voice at 15 feet with each ear without hearing aid								
HA Use Allowed?	N	N	N	N									Y
Further Testing if Don't Pass?	Full audiological evaluation and HINT												Only allowed in further testing SPT, WR in quiet and noise
<b>U.S. Dept. of Interior—Surface Mining Reclamation Specialists<sup>8</sup></b>													
500	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
1000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
2000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
3000	≤40 dB	≤45 dB	≤45 dB	≤45 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB
4000		≤45 dB	≤45 dB	≤45 dB									
6000		≤25 dB including 3000 Hz											
PTA (500, 1000, 2000)		PE PTA not more than 15 dB worse than BE PTA; 4000 and 6000 Hz in PE not more than 30 dB worse than in BE											≤25 dB at 1000, 2000, and 3000 Hz
Other Required Criteria					Must be able to hear whispered voice at 15 feet with each ear without hearing aid								
HA Use Allowed?	N	N	N	N									Y
Further Testing if Don't Pass?	Full audiological evaluation and HINT												Only allowed in further testing SPT, WR in quiet and noise
<b>U.S. Dept. of Homeland Security—Border Patrol Agents<sup>9</sup></b>													
500	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
1000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
2000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
3000	≤40 dB	≤45 dB	≤45 dB	≤45 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB
4000		≤45 dB	≤45 dB	≤45 dB									
6000		≤25 dB including 3000 Hz											
PTA (500, 1000, 2000)		PE PTA not more than 15 dB worse than BE PTA; 4000 and 6000 Hz in PE not more than 30 dB worse than in BE											≤25 dB at 1000, 2000, and 3000 Hz
Other Required Criteria					Must be able to hear whispered voice at 15 feet with each ear without hearing aid								
HA Use Allowed?	N	N	N	N									Y
Further Testing if Don't Pass?	Full audiological evaluation and HINT												Only allowed in further testing SPT, WR in quiet and noise
<b>U.S. Dept. of Homeland Security—Border Patrol Agents<sup>9</sup></b>													
500	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
1000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
2000	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB	≤30 dB
3000	≤40 dB	≤45 dB	≤45 dB	≤45 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB	≤40 dB
4000		≤45 dB	≤45 dB	≤45 dB									
6000		≤25 dB including 3000 Hz											
PTA (500, 1000, 2000)		PE PTA not more than 15 dB worse than BE PTA; 4000 and 6000 Hz in PE not more than 30 dB worse than in BE											≤25 dB at 1000, 2000, and 3000 Hz
Other Required Criteria					Must be able to hear whispered voice at 15 feet with each ear without hearing aid								
HA Use Allowed?	N	N	N	N									Y
Further Testing if Don't Pass?	Full audiological evaluation and HINT												Only allowed in further testing SPT, WR in quiet and noise

Table 1. Continued

Test Frequencies (Hz)	Federal Mine Health and Safety Series <sup>8</sup>	Federal Air Traffic Control <sup>8</sup>	Federal Motor Carrier Safety Administration Commercial Motor Vehicle Operators and Longer Combination Vehicle Driver Instructors <sup>12</sup>	Michigan State Police <sup>13</sup>	New York Entry-Level Police Officer Candidates <sup>14</sup>	New Hampshire Police/Corrections Academy <sup>15</sup>	Frederick County, Maryland, Firefighters <sup>16</sup>	Wildland Arduous Firefighters <sup>17</sup>
500	≤40 dB	≤20 dB BE ≤25 dB PE	≤20 dB BE ≤25 dB PE	≤20 dB	≤25 dB	≤40 dB		≤40 dB
1000	≤40 dB	≤20 dB BE ≤25 dB PE	≤20 dB BE ≤25 dB PE	≤20 dB	≤25 dB	≤40 dB		≤40 dB
2000	≤40 dB	≤20 dB BE ≤25 dB PE	≤20 dB BE ≤25 dB PE	≤20 dB	≤25 dB	≤40 dB		≤40 dB
3000		≤40 dB	≤40 dB	≤20 dB	≤30 dB Cannot be "abnormal"	≤40 dB		≤40 dB
4000				≤20 dB				
6000								
PTA (500, 1000, 2000)			≤40 dB or perceives forced whispered voice in BE at not less than five feet			≤25 dB including 3000 Hz; or able to hear "whispered conversation" at 15 feet. Prefer audio results.	PE ≤30 dB including 3000 Hz	
Other Required Criteria							PE ≤25 dB at 500, 1000, or 2000 Hz and ≤35 dB at 3000 Hz; or PE ≤30 dB at 500, 1000, or 2000 Hz	
HA Use Allowed?	Y		Y	Only allowed in further testing WR in quiet and in noise	Y		N	N
Further Testing If Don't Pass?					Audiogram, WR in quiet and noise			

Note: Threshold information is dB HL. All hearing threshold levels refer to both ears unless separate thresholds are given for the better ear (BE) and poorer ear (PE). Blank boxes indicate that no information was available. The authors made considerable efforts to find the most current information available; however, the currency of the information in the table cannot be guaranteed. HA = hearing aid; HINT = Hearing in Noise Test; PTA = pure-tone average; SRT = speech recognition threshold; WR = word recognition.

- References:
1. Department of the Air Force (2006)
  2. Department of Defense (2005)
  3. Department of the Army (2007)
  4. Department of the Navy (2005)
  5. U.S. Air Force Academy (2008)
  6. Department of the Army (2006)
  7. U.S. Department of Interior Law Enforcement (1998)
  8. U.S. Office of Personnel Management (1999)
  9. U.S. Department of Homeland Security (2008)
  10. U.S. Department of Justice
  11. U.S. Office of Personnel Management (1998)
  12. Federal Motor Carrier Safety Administration
  13. Michigan Commission on Law Enforcement Standards (2004)
  14. New York State Municipal Police Training Council (2006)
  15. New Hampshire Police Standards and Training Council (2004)
  16. Marsh (1997)
  17. National Interagency Fire Center
  18. U.S. Marshals Service

**Table 2. Hearing Profiles for U.S. Army and U.S. Air Force Personnel**

Profile	U.S. Army <sup>1</sup>	U.S. Air Force <sup>2</sup>
H1	PTA $\leq$ 25 dB @ 500, 1000, and 2000 Hz with no single threshold $>$ 30 dB $\leq$ 35 dB @ 3000 Hz $\leq$ 45 dB @ 4000 Hz	$\leq$ 25 dB @ 500, 1000, and 2000 Hz  $\leq$ 35 dB @ 3000 Hz $\leq$ 45 dB @ 4000 and 6000 Hz
H2	PTA $\leq$ 30 dB @ 500, 1000, and 2000 Hz with no single threshold $>$ 35 dB $\leq$ 45 dB @ 3000 Hz $\leq$ 55 dB @ 4000 Hz If asymmetry, BE cannot be $>$ 30 dB @ 500 Hz, $>$ 25 dB @ 1000 and 2000 Hz, and $>$ 35 @ 4000 Hz (PE may be deaf)	$\leq$ 35 dB @ 500, 1000, and 2000 Hz  $\leq$ 45 dB @ 3000 Hz $\leq$ 55 dB @ 4000 Hz
H3	SRT in better ear $\leq$ 30 dB with or without hearing aid	Hearing loss greater than H2
H4	Hearing loss worse than H3	Hearing loss that precludes safe/effective job performance regardless of level of pure tone hearing loss, with or without hearing aids

Note: Threshold information is in dB HL. See text for details. BE = better ear; PE = poorer ear.

References:

1. Department of the Army (2007).
2. Department of the Air Force (2006).

criteria for U.S. military departments including the Coast Guard stipulate that both ears must pass identical threshold criteria (Department of Defense, 2005). The California Commission on Peace Officer Standards and Training (POST), which provides minimum suggested fitness guidelines for law enforcement agencies in California (S.W. Spilberg, pers. comm., Apr. 3, 2008), stipulates that threshold differences between ears should not exceed 15 dB at 500, 1000, and 2000 Hz, and 30 dB at 3000, 4000, and 6000 Hz (Goldberg, 2001). In some cases, assistive technology, such as hearing aids, may be used during AFFD testing; however, this varies among jobs as can be seen in Table 1.

Notably, most pure-tone AFFD standards have cutoff values at one or more frequencies that, strictly speaking, constitute a hearing loss (defined by audiologists as thresholds greater than 20 dB HL re: ANSI S3.6-2004 [American National Standards Institute, 2004]). For example, as shown in Table 1, the U.S. armed forces allow an individual with a mild to moderate high-frequency hearing loss to enlist. However, as is discussed below, audiometric pass-fail criteria were originally based on medico-legal definitions of handicapping hearing loss, not on fitness-for-duty concerns (MacLean, 1995). Further, "normal hearing," as defined *audiologically*, is usually not necessary to perform even most hearing-critical jobs, since detection of sounds at extremely low levels in quiet is rarely required. Nevertheless, the question as to what degree of hearing loss is handicapping for a given job is an important one, and current AFFD pass-fail criteria do not provide an answer.

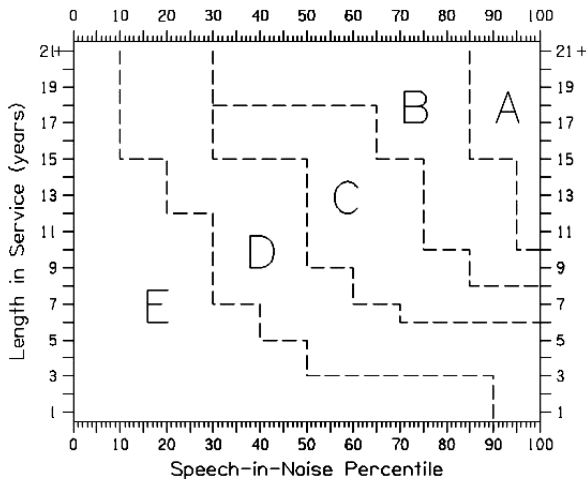
### Additional AFFD Testing

AFFD test protocols currently in use generally comprise pure-tone threshold testing with additional testing as necessary. Additional tests usually include speech-in-quiet or speech-in-noise tests and are referred to as "functional exams," because they purportedly relate more closely to job functions than does the audiogram. In most cases, additional AFFD testing is conducted only when individuals do not meet pure-tone threshold criteria.

Some organizations categorize individuals according to their pure-tone hearing thresholds in order to evaluate the need for additional testing or job restrictions (see Table 2). For example, the U.S. Army and Air Force use "profiles" to categorize enlisted service members based upon their thresholds (Department of the Air Force, 2006; Department of the Army, 2007). The H-1 profile essentially designates normal hearing (although mild-to-moderate loss is permitted above 2000 Hz). A person with an H-1 profile is considered fit for any Army or Air Force assignment; no further testing is needed (MacLean and Danielson, 1996; Forshaw and Hamilton, 1997; Department of the Air Force, 2006; Department of the Army, 2007). An H-2 profile indicates some hearing loss. Individuals with an H-1 or H-2 profile are immediately deployable (Sobieraj et al, 2006), but some job restrictions may be imposed on individuals with an H-2 profile (Department of the Air Force, 2006; Department of the Army, 2007). As noted above, while both H1 and H2 profiles indicate acceptable hearing acuity for deployment, not all of the pure-tone thresholds meet audiological

## CATEGORY RECOMMENDATION

- A Retention in current assignment
- B Retention in current assignment with restrictions
- C Re-assignment to (or retention in) non-noise hazardous AOC/MOS
- D Discretionary
- E Separation from service



**Figure 1.** Chart depicting SPRINT score and length of service. The letter category is used to determine the appropriate recommendation for an individual soldier. From Cord et al (1992).

criteria for “normal” hearing (see Table 2). Generally, this is not a problem, especially if important speech and sounds are at suprathreshold levels. However, depending on the particular situation or job, even a mild hearing loss could affect performance. Tinning (1973) noted that mild losses could result in decreased localization ability, yet the H2 profile permits asymmetry in hearing thresholds such that the poorer ear may be deaf. Clearly, the H1 and H2 profiles do not guarantee “normal” auditory function for soldiers or airmen.

Army and Air Force personnel are profiled as H-3 or H-4 when there is “substantial” hearing loss. Individuals with these profiles may be significantly limited in their job choices or may even be separated from service. Personnel with H-3 or H-4 profiles must undergo additional functional testing regardless of their military occupational specialty. The functional exam includes unaided speech-in-noise testing (Department of the Army, 2007; Navy Environmental Health Center, 2007).

The results of functional exams can assist in the placement of individuals with hearing loss. Work experience and the specific job that is being sought may also influence placement (Cord et al, 1992; Chandler, 2005). The U.S. Army uses scores on the Speech Recognition in Noise Test (SPRINT) (Cord et al, 1992) together with length of service to determine

service retention, reassignment, or separation for soldiers with H-3 or H-4 profiles. As can be seen in Figure 1, an individual with a SPRINT score of 50% and 20 years of service will be placed in category B; this individual will be allowed to remain in his or her assignment, with restrictions. However, an individual with the same SPRINT score and only two years of service will be placed in category E, and separation from service will be recommended.

In general, job candidates who do not meet AFFD standards are either recommended to be restricted from safety-sensitive tasks, restricted from noisy environments, or dismissed from employment (Begines, 1995; MacLean and Danielson, 1996; Goldberg, 2001). The final determination is often left to an occupational physician or personnel officer, sometimes in consultation with an audiologist. For example, once a soldier is profiled and has a SPRINT score, a military audiologist consults with the Medical Evaluation Board (MEB) or Physical Evaluation Board (PEB) (Department of the Army, 2007) regarding the soldier’s hearing status. Military commanders or personnel management officers then make the final determination regarding a waiver for employment or continued employment, or reclassification into a different job (Begines, 1995; MacLean and Danielson, 1996). If the job is hearing critical, as in the case of a pilot, it is unlikely that a waiver will be granted. In difficult-to-fill professional positions, such as doctors, nurses, and lawyers, hearing loss may not be a reason for dismissal (Chandler, 2005).

### Ascendancy and Limitations of the Pure-Tone Audiogram

In the past, free-field live-voice tests were common in clinical and occupational assessment of hearing. The forced-whisper test is still utilized by the Federal Highway Administration for AFFD testing for commercial motor-vehicle operation. Applicants must be able to perceive a forced whispered voice in at least one ear at not less than five feet, with or without use of a hearing aid (Federal Motor Carrier Safety Administration). Such tests, while possessing face validity, are fraught with limitations, including “inadequate test protocols, calibration, and interpretative criteria” (Jones and Hughes, 2001). Today, the pure-tone audiogram has largely replaced free-field live-voice tests as the most commonly accepted measure of auditory fitness.

One of the original purposes of pre-employment hearing testing was to safeguard employers against civil claims by ascertaining whether hearing loss was present prior to employment (Jones and Hughes, 2001). Ongoing, on-the-job hearing testing serves to protect both the employer and the employee by alerting

them to the progression of hearing loss. Thus, audiometric pass-fail and profiling criteria were originally based on medico-legal definitions of handicapping hearing loss, not on fitness-for-duty concerns (MacLean, 1995).

Moreover, pure-tone audiometry measures monaural, peripheral auditory function in quiet, while good functional hearing typically requires spatial awareness of sounds and speech at suprathreshold levels, often in background noise (Laroche et al, 2008). Thus, the ability to perform hearing-critical job tasks or communicate effectively cannot be accurately assessed with the audiogram alone (Marshall and Carpenter, 1988; Goldberg, 2001; Jones and Hughes, 2000). In fact, the audiogram often underpredicts the functional performance of individuals with hearing loss (Soli, 2003). Experience, skill on the job, and familiarity with typical communications, warning signals, and job protocols may allow an employee to compensate successfully for hearing loss (Jones and Hughes, 2000; Dobie, 2001; Goldberg, 2001). The opposite can also occur, though much less often: an individual with a normal pure-tone audiogram may have difficulty communicating effectively in noise, secondary to traumatic brain injury (Gallun et al, 2008) or to central auditory nervous system pathology (Middleweerd et al, 1990; Stach, 2000).

Today, preexisting hearing impairment as demonstrated by pure-tone audiometry is not sufficient to deny employment in many cases. Since the implementation of the Americans with Disabilities Act (ADA; U.S. Department of Labor, 2007), exclusionary criteria for employment must be shown to be job related and consistent with business necessity. In addition, it must be demonstrated that the job cannot be performed with reasonable accommodations. (Note that the ADA only applies to private companies of 15 or more employees, state and local government positions, employment agencies, labor unions, and joint labor-management committees. U.S. government executive agencies are exempt from the ADA; however, they must comply with similar nondiscrimination requirements under Section 501 of the Rehabilitation ACT of 1973 [Equal Employment Opportunity Commission {EEOC}, 1992]). The legality of AFFD test protocols based on pure-tone audiometry has been tested in court (e.g., Laroche, 1994; Laroche et al, 2003; Seyfarth Shaw LLP, 2006; Audiology Online, 2008; Ceniceros, 2008). The outcomes of these cases demonstrate the tendency of the legal system to support AFFD standards that clearly relate to job requirements. In one complaint brought against the Department of Fisheries and Oceans Canada (DFO) in 1995, a job applicant alleged that he was wrongly refused a job because of an asymmetric hearing loss. The Canadian Human Rights Commission determined that the DFO's use of audiometric

thresholds as the sole determinant of AFFD was insufficient since suprathreshold hearing abilities that were critical to job performance, such as localization and speech perception in noise, were not evaluated (Laroche et al, 2003). This outcome led to the establishment of an AFFD protocol that included functional measures of hearing in noise.

In recent years, scrutiny of AFFD protocols has been motivated by legal considerations in the civilian sector and by the impetus of mission accomplishment coupled with high rates of traumatic brain injury in the military. In both the military and civilian sectors, the underlying question is the same: how do we move from a pure-tone-audiometry-based AFFD protocol to one that reliably and validly assesses the functional hearing abilities necessary to successfully perform a job or accomplish a mission? Before considering this question more fully, we describe the functional hearing abilities common to hearing-critical jobs.

### FUNCTIONAL HEARING ABILITIES REQUIRED TO PERFORM HEARING-CRITICAL TASKS

For some job tasks, the ability to hear is absolutely critical; neither job experience nor the supplementation of auditory cues with cues from other sense modalities can compensate for limitations in hearing. For example, the unassisted ability to detect and localize sounds made by unseen adversaries in combat is wholly dependent on hearing ability. Such tasks are *hearing-critical* (Laroche et al, 2003; Soli, 2003). According to Laroche et al (2003), a task is hearing-critical only if it can be performed to a specified level of accuracy by a normal-hearing person using the sense of hearing alone. For example, hearing whispers on a noisy shop floor cannot be considered a hearing-critical task because even people with normal hearing cannot do this (although a person with either normal hearing or hearing loss may be able to understand the whispered message through visual cues or other means).

In some cases, an experienced worker who has gradually lost some hearing due to age, noise exposure, or other causes may be able to function safely and effectively in environments in which more inexperienced workers with the same degree of hearing loss would be at risk. Such workers compensate for limitations in hearing ability by relying on other sense modalities (e.g., vision, touch), or on skills, knowledge, and experience accumulated over time. For convenience, tasks for which hearing loss would be a liability in inexperienced workers will be considered hearing-critical in this article, though we recognize that we are taking some liberty with Laroche et al's (2003) definition.



A description of hearing-critical tasks specific to different professions is beyond the scope of this review. The AFFD literature describes examples of hearing-critical tasks in law enforcement (Punch et al, 1996; Cook and Hickey, 2003), the military (Price et al, 1989; Garinther and Peters, 1990), and industry (Héту, 1994; Héту et al, 1995). Hearing-critical tasks require the ability to detect, recognize, and localize sounds, and to understand speech. These abilities are sometimes referred to as “functional hearing abilities” (Soli, 2003) or in the aggregate as “functional hearing” (Cook and Hickey, 2003). Broadly, functional hearing abilities allow one to maintain contact with the acoustic environment and to communicate via speech (Soli, 2003). Functional hearing emphasizes the *use* of hearing, and as such may be distinguished from basic psychoacoustic capabilities such as pure-tone detection, frequency resolution, temporal resolution, and so on. In the following, we describe each of the functional abilities.

### Sound Detection and Recognition

In many job situations, an individual must be able to detect sounds that require investigation. Some of these sounds may be very soft, such as breathing sounds or the stealthy movements of an adversary. Others may be louder or may occur in a background of noise. Emergency situations often require the detection of warning signals or unexpected sounds.

Sound detection is fundamental to all other functional hearing abilities. Without it, recognition, localization, and speech understanding cannot take place. An assessment of the ability to detect sounds is part of all AFFD protocols and almost always consists of the measurement of pure-tone thresholds in quiet (*viz.*, the audiogram). The thresholds obtained on the audiogram are compared to average thresholds for young, otologically normal listeners (*i.e.*, 0 dB HL [ANSI S3.6-2004; American National Standards Institute, 2004]). Clinically, thresholds that are 25–40 dB worse than average signify mild hearing loss; thresholds 41–55 dB worse than average signify moderate hearing loss; and so on. These somewhat arbitrary clinical categories serve as a point of reference but are not especially helpful for deciding whether a particular individual is fit for duty.

In quiet, the limiting factor for detection is the individual’s threshold in quiet; therefore, pure-tone detection thresholds can predict a person’s ability to hear in quiet fairly well (*e.g.*, Kamm et al, 1985). In noise, normal-hearing individuals and those with hearing loss alike experience greater difficulty hearing signals. However, persons with sensorineural hearing impairment are generally more susceptible to the effects of masking by noise. They typically require greater signal-to-noise ratios (SNRs) (on the order of

5–25 dB) to detect sound, especially if it is unexpected or incidental, compared with normal-hearing people (Coles and Sinclair, 1988; Héту et al, 1995). Mean SNR needed for signal detection increases with decreased hearing sensitivity at the signal frequency, especially for hearing thresholds greater than 30 dB HL (Héту et al, 1995). Complicating matters further, individuals with the same thresholds in quiet may vary widely in their thresholds for detecting sounds in noise. These differences may result from varied patterns of outer and inner hair cell loss or damage (Moore, 2007). Thus, the relationship between the pure-tone audiogram and the detection of signals in noise is not straightforward. Signal detection in noise is not commonly assessed clinically or in AFFD protocols, despite its importance in work and combat environments.

Sound detection can be affected if hearing protection devices (HPDs) are worn. Typically, conventional HPDs do not have a significant effect on masked thresholds for normal-hearing individuals in noise above 80 dBA, but they can adversely affect audibility in lower noise levels (Casali et al, 2004). (However, HPDs are not usually necessary in low-noise environments.) For people with hearing loss, HPDs can attenuate sounds to be below threshold and therefore undetectable (Abel et al, 1993; Berger, 2000).

Cognitive loading, or the burden placed on working memory during the performance of a task, may affect sound detection in noisy work environments for individuals with hearing loss, especially if the sound is unexpected. Detection thresholds can worsen by 6–9 dB or even more from normal inattention alone (Wilkins and Martin, 1978). Wilkins (1984) assessed the effectiveness of intentional and incidental warning signals (a horn, and metal components falling from a container, respectively) under real factory conditions while employees with and without hearing loss wore HPDs. Subjects’ hearing losses ranged from “mild” (sum of hearing levels from 500 to 6000 Hz exceeding 45 dB) to “substantial” (sum of hearing levels from 500 to 2000 Hz equal to or greater than 60 dB and sum of hearing levels from 3000 to 6000 Hz equal to or greater than 75 dB). All subjects listened for the signals while performing everyday job tasks and while sitting idly. Normal-hearing and hearing-impaired subjects’ ability to detect the intentional signal was unimpaired in both the working and idling conditions even while wearing HPDs. However, when subjects were distracted by performing their everyday job duties, the incidental signal was not detected as well by those with substantial hearing loss as it was by subjects with normal hearing or mild hearing losses. Wearing HPDs led to further difficulties in identifying the incidental signal in subjects with substantial hearing loss, due to the high-frequency attenuation characteristics of the HPDs. This study demonstrates that cognitive loading

may have a detrimental effect on sound detection for incidental warning signals in people with hearing loss, especially when they wear HPDs.

Hearing aids are frequently worn by individuals with hearing loss. Although hearing aids amplify sound, they do not restore sound detection to normal. Early prescriptive fitting procedures held the philosophy that the amount of gain necessary at a specific frequency was equal to the threshold loss at that frequency, minus a constant proportion of the threshold loss (Dillon, 2001). In this way, the shape of the hearing loss on the audiogram was mirrored, but detection thresholds were not restored to normal. The amount of gain necessary to restore thresholds to normal would cause moderate-to-high-level sounds to be prohibitively loud. In today's more complex nonlinear fitting algorithms, the goal is still to maximize speech intelligibility, not to restore sound detection to normal (Dillon, 2001; K. Cienkowski, pers. comm., Dec. 10, 2008).

Workers must not only be able to detect relevant signals, but they must also be able to recognize them and understand the message they convey in order to respond appropriately (Punch et al, 1996; Hager, 2002; Cook and Hickey, 2003). For example, workers should be able to recognize telltale sounds of malfunctioning equipment (Forshaw and Hamilton, 1997; Morata et al, 2005), or recognize other meaningful signals such as backup alarms, horns on approaching vehicles, sirens, whistles, or bells, usually in a background of noise (Lee et al, 1981; Coles and Sinclair, 1988; Punch et al, 1996; Forshaw and Hamilton, 1997; Hager, 2002; Cook and Hickey, 2003; Morata et al, 2005). Submarine sonar operators identify brief-duration signals as friend or foe based on auditory cues buried in background noise (L. Marshall, pers. comm., Aug. 8, 2008). Sound recognition is typically not assessed in AFFD protocols.

### Sound Localization

Cook and Hickey (2003) define localization as "the ability to gauge the direction and distance of a sound source outside the head." Depending on job requirements, a worker may need to be able to identify where the source of the sound is located, whether the source is stationary or moving, and the direction in which it is moving (e.g., approaching or retreating). For example, the ability to localize may be necessary to determine the location of an enemy (Price et al, 1989), the origin of a gunshot (Goldberg, 2001), or the location of buoys at sea in conditions of reduced visibility (Forshaw and Hamilton, 1997), as well as to maintain situational awareness in all settings. The ability to move the head can assist greatly in localizing sounds, if the sounds are of sufficient duration (Moore, 2007).

Hearing loss can adversely impact localization ability. Noble et al (1994) associated hearing in the

low and middle frequencies with the ability to maintain accurate horizontal-plane localization, and hearing levels in the 4–6 kHz range with front-back discrimination and vertical-plane discrimination. According to Tønning (1973), even mild bilateral hearing losses can affect localization ability in some subjects. Durlach et al (1981) reviewed 14 studies of localization and lateralization in people with unilateral and bilateral symmetrical sensorineural hearing loss. In these studies, subjects with unilateral hearing loss tended to perform poorly. On the other hand, subjects with symmetrical hearing losses often had near-normal performance, especially if the intensity of the sounds was high, although variability in performance was great. Sensation level is an important factor in the performance of people with sensorineural hearing loss, because even individuals with normal hearing tend to perform poorly on localization tasks at sensation levels lower than 20 dB (Hausler et al, 1983).

The use of hearing protection devices (HPDs) can affect localization by interfering with spectral location cues provided by the pinna, especially when earmuffs are worn (Russell, 1977). Errors in front-back discrimination are particularly frequent. Hearing aids can impact localization ability as well if signal processing delays interfere with interaural timing cues (Moore, 2007). In addition, when hearing aids are coupled to the ear, pinna cues needed for front-to-back and vertical localization may be eliminated.

Localization ability is generally not tested explicitly in AFFD protocols, even if hearing loss is present. Few localization tests are available, and the equipment and facilities required may not be available. The Source Azimuth Identification in Noise Test (SAINT; Vermiglio et al, 1997) presents sounds of pistol shots and female vocalizations through a 12-speaker array. The listener must localize these signals in quiet and in either helicopter or crowd noise for different presentation azimuths. The Auditory Localization Evaluation System (SELA; Dufour et al, 2005) uses an 11-speaker array. The subject is seated on a swivel chair and identifies from which speaker the 65 dBA broadband noise or other auditory stimulus originates, using either verbal responses or pointing with a head-mounted laser apparatus. These tests are impractical for general clinical use and are not utilized in AFFD protocols. If localization ability is considered at all, it is usually done implicitly. For example, Punch et al (1996) "considered the general contribution of symmetrical hearing sensitivity to localization" when developing AFFD criteria for law enforcement.

### Speech Understanding

Following Soli (2003), speech is considered separately from the detection and recognition of other sounds

because of its importance, uniqueness, and universality. In many situations, workers must be able to understand speech and communicate verbally on the job. It may be necessary to understand verbal messages without the benefit of visual cues, as in low-visibility situations or darkness, while using a radio or telephone, or while driving. The worker must be able to understand verbal messages that are incomplete, distorted, or filtered, as may occur when communication takes place in noise or via communications equipment such as radios or cellphones (Cook and Hickey, 2003). In addition, workers may be required to communicate with persons with foreign or regional accents or other speech/language barriers.

Speech understanding in quiet is routinely assessed clinically, most commonly with monosyllabic words but also with nonsense syllables and/or isolated sentences (Working Group on Speech Understanding and Aging, 1988). However, these stimuli are not typical of everyday speech. Thus, a listener's speech understanding score may not reflect his or her ability to carry on a conversation in quiet, for example.

Speech understanding is affected by hearing loss. At risk of overgeneralizing, individuals with pure-tone averages (PTAs) at 500, 1000, and 2000 Hz of 26–40 dB HL will have marginal difficulty understanding speech in quiet environments. Those with PTAs of 41–55 dB HL will have difficulty in quiet environments unless they are facing the speaker and the vocabulary is constrained. Individuals with PTAs greater than 55 dB HL will have trouble understanding even loud speech in a quiet environment (Tye-Murray, 2004). Threshold elevation is not the only factor that affects speech understanding, however. In a study by Turner and Robb (1987), individuals with normal hearing and with hearing loss identified stop consonants presented at a range of intensity levels in quiet. For the normal-hearing group, performance was at or very close to 100% correct when most of the speech spectrum was above threshold. However, for the individuals with hearing loss, scores did not reach 100% even when the entire speech spectrum was audible. Turner and Robb (1987) concluded that reduced audibility was not sufficient to explain the poor consonant recognition in these subjects. According to Plomp (1978), sensorineural hearing loss is associated with distortion as well as attenuation of speech sounds, mainly due to diminished frequency selectivity.

People with hearing loss experience particular difficulty understanding speech in the presence of background noise. In noisy environments, both the speech and the background noise may be above the listener's threshold, thus overcoming the attenuation aspect of the hearing loss. However, the listener with hearing loss generally requires a more favorable signal-to-noise ratio (SNR) than the normal-hearing

listener, due to the distortion component of the hearing loss (Plomp, 1978). This phenomenon is sometimes referred to as "SNR loss" (Killion et al, 2004). The amount of SNR loss experienced by individuals with mild-to-moderate sensorineural hearing loss is highly variable and cannot be predicted reliably from the audiogram. Even a mild hearing loss can be detrimental to performance in noise (Plomp, 1978). Hearing aids can improve speech understanding by amplifying speech sounds above threshold, but an increase in SNR is usually necessary in addition to amplification to maximize a hearing-impaired individual's potential to understand speech.

Speech understanding in the presence of background noise is often essential for job performance and worker safety. However, it is not consistently assessed in AFFD protocols. When speech-in-noise testing is administered at all, it is usually done in response to a pure-tone loss on the audiogram. However, it is possible to have a normal pure-tone audiogram but still experience difficulty understanding speech in noise, due to poor temporal resolution or other central auditory system disorder (Middleweerd et al, 1990; Stach, 2000) or injury (Gallun et al, 2008). Moreover, with experience, some individuals who work in noisy environments may actually come to perform better than laboratory subjects with equivalent hearing levels (Acton, 1970).

A number of speech-in-noise tests are available for clinical use, including the Speech Perception in Noise test (SPIN; Kalikow et al, 1977), the Speech Recognition in Noise test (SPRINT; Cord et al, 1992), the Words in Noise Test (WIN; Wilson, 2003), the Hearing in Noise Test (HINT; Nilsson et al, 1994) and the QuickSIN (Etymotic Research, 2006; Killion et al, 2004). Some of these tests employ a fixed SNR and give a percentage correct score. The SPIN requires the listener to repeat the last word of each of 50 sentences in the presence of 10-talker babble at a fixed SNR of 8 dB. Half of the target words have low predictability in relation to the rest of the sentence and half have high predictability. The number of correct responses for each type of sentence is totaled, and a "percent hearing for speech in noise" score is derived (Kalikow et al, 1977). The SPRINT is used by the U.S. Army to assess a soldier's potential communication handicap. 200 monosyllabic words are presented binaurally at 50 dB HL with noise fixed at 9 dB SNR. The soldier's score is converted to a percentile rank (Cord et al, 1992; see Figure 1 and the section above titled "Additional AFFD Testing" for more information about the SPRINT).

Other tests vary the SNR at which stimuli are presented and give a threshold measure for speech in noise. The WIN is used within the Veterans Health Administration to find the SNR at which a listener's

word recognition performance is 50%. Monosyllabic words are presented in multitalker babble at seven different SNRs, ranging from 0 to 24 dB in 4 dB increments (Wilson, 2003). The HINT measures thresholds for sentences in quiet and in noise. The noise is fixed in level; the level of the sentences is roved to find the patient's speech threshold (Nilsson et al, 1994). This test has been implemented in several AFFD protocols due to its wide availability and standardization (Goldberg, 2001; Laroche et al, 2008). The QuickSIN measures the SRT in noise using sentence stimuli presented in a background of four-talker babble. The sentences are presented at 70 dB HL for individuals with PTAs less than 45 dB HL or at a level that is "loud but OK" for those with PTAs of 50 dB HL or higher. Sentences are prerecorded at SNRs of 0–25 dB. The difference between the patient's SRT and the SRT for normally hearing people is his or her "SNR loss" (Killion et al, 2004; Etymotic Research, 2006).

Of the organizations listed in Table 1, five stipulate some form of word-recognition testing if puretone threshold criteria are not met. There is no consensus among these organizations as to which speech tests are to be used for AFFD testing. Some organizations do not even specify the test or the pass-fail criteria to be used. For example, the U.S. Marshals Service indicates that certain scores must be achieved on word-recognition tests in quiet and in noise, but the preferred tests and signal-to-noise ratios are not provided (U.S. Marshals Service). As a result, critical aspects of speech testing are left open to interpretation. In any case, satisfactory performance on a clinical speech-in-noise test is not satisfactory evidence that an individual has hearing sufficient to perform hearing-critical job tasks. The relationship between performance on the test and performance on the job must be established beforehand.

In work environments where noise levels exceed 85–90 dBA, workers should wear HPDs consistently. HPDs can improve the ability of normal-hearing listeners to understand speech at these levels, depending on the signal-to-noise ratio. This is because HPDs reduce the overall level of speech plus noise, which results in less distortion in the cochlea (Berger, 2000). However, HPDs may affect speech perception in individuals with limited English proficiency even if hearing is normal (Soli, 2003). In environments with lower or intermittent noise levels, HPDs will tend to decrease speech understanding in both normal-hearing and hearing-impaired listeners (Berger, 2000).

The effect of HPDs on speech understanding in individuals with hearing loss is more difficult to generalize. In these individuals, HPDs can reduce the level of speech (or parts of the speech spectrum) below the audibility threshold. This effect is true for

individuals with even slight high-frequency hearing loss, due to the high-frequency attenuation characteristics of HPDs. Although no firm conclusions can be drawn regarding the level of hearing loss that will degrade speech understanding in noise under HPDs, the results of Lindeman (1976) suggest that a puretone average at 2, 3, and 4 kHz of greater than about 35 dB HL will negatively affect speech understanding when HPDs are worn in noisy environments. A person with hearing impairment is at a particular disadvantage in emergency situations in which speech communication, especially of an unexpected nature, may be critical. Due to the hearing loss, the individual may be less able to take advantage of redundancy and contextual cues in the verbal message (Hétu et al, 1995).

### DEVELOPMENT OF AN AFFD PROTOCOL

The development of an AFFD protocol that is valid, reliable, and consistently and appropriately implemented involves the consideration of several factors. These include, but are not limited to, the following: (1) the auditory demands of the job; (2) the interaction of auditory demands with physical and cognitive demands, job experience, availability of visual cues, and other nonauditory factors; (3) the needs and resources of the organization or company that will be using the test protocol; and (4) legal considerations. Discussion of the third and fourth points is beyond the scope of this paper, although we discuss disability accommodation briefly in a later section. Below we focus on consideration of the auditory demands of the job and, to a lesser extent, their interaction with nonauditory factors.

A starting point for the development of an AFFD protocol is the *job analysis*. At its most basic, a job analysis identifies hearing-critical tasks and the environments and conditions in which individuals perform these tasks. This information provides a framework for choosing appropriate AFFD tests and pass-fail criteria based on the specific hearing demands of the job (Punch et al, 1996; Forshaw and Hamilton, 1997; Goldberg, 2001). See Stuntz (1952), Punch et al (1996), Goldberg (2001), and Laroche et al (2003) for examples of job analyses described in the literature.

Generally speaking, a job analysis should identify the following: (1) hearing-critical tasks, including those directly relevant to the job/mission as well as those important for safety; (2) the importance of each hearing-critical task to the job/mission;<sup>1</sup> (3) the types and consequences of potential errors that would result from an inability to perform each task; (4) how often each task is performed, and for how long; (5) the environments/conditions in which each task is performed; and

(6) the minimum acceptable level of performance required to successfully accomplish each task (Stuntz, 1952; EEOC, 1992; Héту, 1994; Punch et al, 1996; Forshaw and Hamilton, 1997; Cook and Hickey, 2003; Laroche et al, 2003). At least initially, the list of hearing-critical tasks that is compiled should be detailed and exhaustive. Job analyses require the coordinated input of job-content experts and audiologists or other hearing specialists. Job-content experts are knowledgeable and experienced individuals within the organization who are intimately familiar with the nature of the job. The audiologist translates information from the job-content experts into hearing-related parameters.

With the information supplied by job-content experts, the audiologist determines (1) which functional hearing abilities are required for each task; (2) how the conditions under which the hearing-critical tasks are performed translate into acoustic/auditory and related factors; and (3) the minimum level of hearing competency required to successfully perform each task. Auditory/acoustic factors may include the medium of communication (e.g., radio), expected voice/signal levels, distance of verbal communications/signals, whether repetition of commands/signals is possible, whether and what type of HPDs are worn, ambient noise levels, reverberation, and other characteristics of the acoustic environment. Related factors may include availability of visual cues (e.g., speechreading, hand signals, warning lights); lighting conditions; concurrent physical, cognitive, and attentional demands on the worker; job experience; and familiarity with the task.<sup>2</sup> The audiologist must be aware of a possible tendency to overestimate the amount of auditory information that a person is able to receive under given acoustic conditions, or the amount of auditory information that must be received in order to successfully perform a task. For example, Laroche et al (2003) found that speech was not intelligible at the performance levels specified by job-content experts under the conditions that the experts themselves had described as occurring on the job. As a precaution, the audiologist and job-content expert together should review the hearing-critical tasks that have been identified in order to assess whether each task is truly hearing-critical, and if the minimum level of performance identified for each task is realistic (i.e., can be met by a normal-hearing person).

The development of the AFFD test protocol proceeds with the selection of a testing approach. One approach advocates the development and use of tests that mimic hearing-critical situations in specific work environments (MacLean, 2001). The use of real-world simulations has high face validity and may be indicated for jobs involving extreme danger or life-threatening situations (e.g., combat, firefighting, and piloting).

Real-world simulations have the advantage of taking into account nonauditory factors that influence task performance, such as visual cues or attentional demands. On the other hand, the development and administration of such tests is costly and time-consuming. In addition, being designed for specific environments, they have limited applicability. The decision as to whether or not to use real-world simulations will be based on a consideration of the resources of the organization, the consequences of failing to hear critical signals, and the nature of the job (e.g., is it feasible to represent the auditory requirements of the job with a single simulation?). If a simulation-type test is chosen, it must of course be validated. Job-content experts should evaluate its verisimilitude, and performance on the test by successful employees (however “successful” is defined) should be used to develop pass-fail criteria.

Because of the investment required to develop and use real-world simulations, most AFFD test protocols comprise standardized tests originally designed for clinical use (e.g., pure-tone audiometry and audiometric speech tests). Clinical tests provide normative values for normal-hearing and hearing-impaired populations, have known reliability, and can be administered easily in any clinical setting. As with simulation-type tests, performance on clinical tests by successful employees should guide the setting of pass-fail criteria.

The advantages of clinical tests come at the potential cost of validity. The relationship between job performance and clinical test results can be tricky to demonstrate, if indeed any relationship exists. Nonauditory influences on task performance become more difficult to evaluate if a standardized clinical test is administered. Recognition and localization may be assessed indirectly, if at all. For example, as noted earlier, although Punch et al (1996) “considered the general contribution of symmetrical hearing sensitivity to localization” when developing AFFD criteria for law enforcement, they did not include a test of localization in their hearing performance standard.

Tests may be developed or adapted for specific purposes. Laroche et al (2003) describe an effort to validate a clinical test (the HINT) for use in an AFFD test protocol for seagoing and land-based positions in the Canadian Coast Guard (CCG) and the Conservation and Protection (C&P) sections of the Department of Fisheries and Oceans Canada (DFO). In that study, job-content experts specified communication parameters such as the expected voice level and distance of verbal communications and whether repetition of commands was possible. Recordings of ambient noise were made in the environments in which hearing-critical tasks were carried out and were then used to recreate these environments in the laboratory. Intelligibility scores of normal-hearing and hearing-impaired

individuals were obtained with the standard version of the HINT and with HINT sentences in the recorded real-world noises. With these data, Laroche and colleagues created a predictive model of speech understanding in various work environments based on standard HINT scores. Next, the communication parameters established by the job-content experts were used to set pass-fail criteria on the HINT for specific tasks. An individual with several job duties with different pass-fail criteria would be required to pass the most stringent of the criteria. The DFO implemented this protocol into the AFFD test battery for the CCG and C&P departments (C. Laroche, pers. comm., Feb. 8, 2008). See Harris (1946, 1957) for another approach to test protocol development. Harris' AFFD test battery for sonar operators included clinical and psychoacoustic tests (e.g., the Harvard Test of Loudness Discrimination for Bands of Noise), and validation was accomplished by relating test performance of sonar operators to ratings of their on-the-job performance by peers and superiors.

Regardless of the approach taken, tests and pass-fail criteria should be chosen keeping in mind the most stringent competency requirements identified for each functional hearing ability for the job. If hearing protection is used on the job, then it should be worn during testing.

### **An Example of a Hearing-Critical Task**

A simple example of a hearing-critical task is given to illustrate the points outlined above. While this example does not involve physical safety, it does require the ability to hear: A violinist in a symphony orchestra tunes his or her instrument on stage immediately prior to a performance. (The violinist tunes at other times under different conditions, and usually tunes the violin at least once before going onstage, but we take this specific instance as our simplified example.) According to the job-content expert, this task is very important; lack of accurate tuning will result in being out of tune with the rest of the orchestra; at least one of the consequences of tuning incorrectly is a botched performance; the task is performed for up to about 30 sec, just prior to the performance; it is performed in good lighting under noisy and relatively stressful conditions; the tuning must be accurate to within several hundredths of a semitone.

With information from the job-content expert, and observation and measurement of the conditions on the stage, the audiologist determines that the functional abilities of detection and recognition are required for this task; tuning is cognitively demanding and requires skill in handling the instrument and familiarity with the process of tuning; attentional resources are directed, for the most part, to the task; no visual cues

are available; the task is performed in a semireverberant environment in relatively high noise levels (perhaps around 85 dBA); the competing sounds are either lower or similar in pitch to the violinist's sounds; the signal-to-noise ratio at the violinist's ear is greater than 0 dB because of the proximity of the instrument to the ear; and the task can be repeated multiple times (within approximately 30 sec) to ensure accuracy. The challenge now remains to determine the minimum level of hearing competency required to successfully complete this task.

If a test of the violinist's tuning ability can be constructed that provides a sufficiently good real-world simulation, then determination of hearing competency per se is moot; the ability to do the task is tested instead. As an example of such a test, the violinist is seated in a well-lit, semireverberant room. Orchestral tuning sounds are played through several loudspeakers at about 85 dBA to recreate the acoustic environment. The violinist's instrument is mistuned by the examiner and then handed to the violinist, who now has 30 sec to tune. After 30 seconds, the violin is removed to a quiet location where the accuracy of the tuning is assessed with an electronic tuner. The violinist passes the test if his or her accuracy falls within the 95% range of accuracy achieved by other symphony orchestra violinists previously tested under the same conditions. Some of the elements of the real-world situation, such as the presence of the audience and the other musicians, would be missing. Job-content experts must evaluate whether or not the test is a sufficiently good simulation.

If a real-world simulation test and associated norms are unavailable, then a proxy test must be found. In the violin-tuning example, a proxy test might include a musical-interval-recognition test and a pitch-matching-in-noise test, with norms developed on other violinists. Pure-tone audiometry would not be appropriate, since tuning is a suprathreshold task that tolerates some hearing loss and not all normal-hearing people can tune accurately.

### **Disability Accommodation**

AFFD testing should not unfairly discriminate against individuals with hearing loss. The Federal Rehabilitation Act of 1973 and Title I of the Americans with Disabilities Act (ADA) together cover federal, state, and local governments, employers who receive federal funding, private employers, employment agencies, and labor organizations. These laws mandate that: (1) an employer cannot discriminate against qualified applicants and employees on the basis of disability (EEOC, 1992, p. 11); (2) an employer must make a reasonable accommodation to the known physical or mental limitations of a qualified applicant or employee

with a disability unless it can show that the accommodation would cause an undue hardship on the operation of its business (p. 15); and (3) if an individual appears to pose a direct threat because of a disability, the employer must first try to eliminate or reduce the risk to an acceptable level with reasonable accommodation. If an effective accommodation cannot be found, the employer may refuse to hire an applicant or discharge an employee who poses a direct threat (p. 16).

Accommodations for hearing loss may include allowing the use of hearing aids, restructuring job requirements, providing qualified interpreters, reassigning job responsibilities or schedules, or providing assistive technologies including telephone amplifiers and visual alerting devices (EEOC, 1992; LaCroix, 1996a; MacLean and Nilsson, 1997).

Two main questions need to be considered regarding accommodation for individuals with hearing loss: (1) Should accommodations be allowed during AFFD testing? and (2) Should accommodations be allowed on the job? According to Title I of the ADA, it may be necessary to allow accommodations during pre-employment examinations in order to assess the true ability of an individual to perform job tasks. However, if job performance relies heavily on the use of the impaired skill or sensory ability, then accommodations during testing or on the job may be denied (EEOC, 1992). In hearing-critical jobs, the use of assistive listening devices (usually hearing aids) is currently allowed in some, but not all, cases. In California, for example, law-enforcement workers may use hearing aids on the job if the aids have been worn for at least one month, if the hearing aids meet electroacoustic standards, and if the applicants meet aided behavioral test standards (Goldberg, 2001). Trained and experienced soldiers with hearing aids are not automatically disqualified from the U.S. Army; they may be returned to duty with some limitations. On the other hand, firefighters (Marsh, 1997; National Interagency Fire Center), U.S. Border Patrol agents (U.S. Department of Homeland Security, 2008), new military recruits (Department of Defense, 2005), and law enforcement and security personnel of the Department of Homeland Security Federal Protective Service (U.S. Department of Homeland Security, 2008) are not permitted to use hearing aids to pass AFFD tests and may even be restricted from using hearing aids on the job entirely. In firefighting, for example, hearing aids are contraindicated because of possible interference with localization abilities, risk of dislodging the hearing aid during emergencies, heat and water damage, feedback from helmets, and the need for hearing protection (L. Cook, pers. comm., June 10, 2008).

If employers allow hearing aids on the job, requirements regarding their use in the work environment must be established. For example, hearing aids must

be intrinsically safe to be used in coal mines and other environments where there are flammable atmospheres (Coles and Sinclair, 1988). As another example, the U.S. Department of Transportation states that a driver who meets hearing requirements with the use of a hearing aid must wear the aid at all times while driving. They must also be in possession of spare power sources for the hearing aid (Federal Motor Carrier Safety Administration).

Even with such requirements in place, practical difficulties can arise with accommodations in hearing-critical jobs. Proper hearing aid use and function is difficult to monitor among employees. Hearing aids may be lost or damaged, especially in harsh work environments. Amplification provided by hearing aids can be compromised by acoustic feedback, cerumen in the ear canal, and weak or dead batteries.

### DIRECTIONS FOR THE FUTURE

Due in large part to legal considerations in the civilian sector and operational demands in the military sector, greater attention is now being paid to AFFD standards than in times past. Although AFFD decisions are ultimately management decisions (Begines, 1995; LaCroix, 1996b), audiologists and hearing researchers should be extensively involved in evaluating AFFD and in developing reliable and valid AFFD protocols. Based on our examination of the research literature and current practices, we offer the following observations and suggestions for future research in these areas.

First, our efforts to define “best practices” in AFFD testing were frustrated by the sheer variety of hearing-critical situations encountered in the workplace, and by the difficulty of accounting for the influence of nonauditory factors on task performance. Two practices we find ourselves recommending are speech testing in noise and the inclusion of 4000 Hz as a test frequency if pure-tone detection thresholds are tested. Yet even these simple recommendations leave many questions unanswered: What type of speech material should be used? What type of noise, speech-to-noise ratio, or measure (threshold or suprathreshold)? What is the pass-fail cutoff for speech testing? For 4000 Hz? and so on. In the end, we decided that we could not answer these questions within the scope of this paper. AFFD test protocols cannot be viewed as “one size fits all.” AFFD testing should be job-specific. Nevertheless, we have two conservative recommendations for best practices in the *development* of AFFD protocols. (For more details, see the section “Development of an AFFD Protocol”). The process should start with a thorough consideration of the job requirements, the demands on the employee, and the work environment(s). Only after this step is taken should hearing ability be considered.

This “order of operations” will help ensure that hearing ability is considered in the context of the multiple factors affecting job performance that may interact with it. Next, “reality checks” are necessary at every step in the development process. For instance, employees who are already performing satisfactorily should be able to pass any AFFD test protocol that is developed for that job. In practice, this means that AFFD test protocols must be flexible enough to accommodate employees who have learned to compensate successfully for loss of hearing. As with any screening test, however, a percentage of false negatives must be expected.

Our second observation is that the pure-tone audiogram is no longer defensible as the sole AFFD test in most cases. Especially for military serving in wartime, this is true even if results show normal hearing. In developing a hearing-performance standard for law-enforcement officers, Punch et al (1996) opined that an individual with normal pure-tone hearing sensitivity could be expected to have normal speech understanding. This assumption is challenged by the number of American soldiers currently returning from Iraq and Afghanistan with traumatic brain injuries due to blast exposures. Anecdotally, a common complaint among these veterans is difficulty understanding speech in noise in spite of normal hearing thresholds (Gallun et al, 2008). Injury to central auditory system structures could disrupt the transmission and processing of temporal, spectral, and binaural information, leading to these complaints (Gallun et al, 2008). Prior to redeploying, personnel exposed to blasts should be evaluated for loss in functional hearing abilities above and beyond pure-tone detection.

Third, the establishment of validity is the single greatest challenge confronting AFFD test protocol development and use. With good reason, an AFFD test protocol that has poor validity will be ignored by management and challenged legally by employees. Widespread inconsistency in pass-fail criteria and enforcement across jobs, sites, and examiners (MacLean, 1995; LaCroix, 1996a; Kales et al, 1998; Soli, 2003; S. Peck, pers. comm., June 30, 2008) reinforces the perception that AFFD tests are meaningless. Establishing validity is bound up with setting pass-fail criteria for AFFD tests and the adoption of accommodation policies. If criteria are too lax, individuals with hearing impairment may be hired despite being unable to perform hearing-critical tasks safely and efficiently, or may be ineligible for workplace accommodation once hired (Forshaw and Hamilton, 1997). On the other hand, if criteria are too stringent, costs to the company or organization may increase due to increased need for accommodations and/or the need to recruit additional employees (S. Peck, pers. comm., June 30, 2008), and workers may be unnecessarily or

unfairly disqualified from jobs they could otherwise perform (Forshaw and Hamilton, 1997). Furthermore, distinguishing among cases in which experience, compensatory strategies, and/or accommodations can and cannot substitute for normal hearing is far from trivial.

Clearly, the development of improved AFFD protocols will only proceed if the benefits of such development (e.g., improved productivity, improved mission success, lower retraining and replacement costs, fewer injuries, fewer lawsuits) are perceived—or better yet, shown—to outweigh the costs in time and money. But the need to institute job-specific AFFD protocols, move beyond the pure-tone audiogram, and establish the validity of test protocols is arguably greater now than in times past. Valid AFFD test protocols will win the cooperation of management because they will be meaningful. This will be the true test of the AFFD protocol.

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## NOTES

1. Harris (1957), in a report of the development of an AFFD test battery for the selection of sonar operators, wrote that “[c]onsiderable time was lost on the false lead of attempting to rate the relative importance to the sonar job of [specific identified tasks]. It was found that for purposes of a validation criterion, the appropriate analysis was rather to find which of the [tasks] clearly differentiated outstanding operators from poor operators” (p. 5). Note, however, that defining a validation criterion is different from conducting an initial job analysis.
2. Other factors may contribute to success in hearing-critical tasks on the job, such as morale and motivation (Harris, 1957), but these fall outside the scope of the AFFD protocol.

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